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Evaluation of pulpal blood flow after tooth splinting of luxated permanent maxillary incisors

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Abstract – Laser Doppler flowmetry (LDF) is a non-invasive method to assess pulpal blood flow (PBF). Dental injury has been associated with losses of pulpal sensibility. The purpose of this study was to assess whether LDF could be used to detect short- and long-term changes of PBF values of luxated permanent maxillary central incisors after repositioning and splinting. In 18 trauma patients, a single maxillary incisor treated by repositioning and splinting, and the respective contralateral homologous tooth were investigated by LDF to assess local PBF values. Perfusion units (PU) were taken in four sessions: on the day of splint removal, and 12, 24, and 36 weeks after splint removal. Analysis of the luxation type-related PBF measurements revealed intrusion type-related PBF values to be associated with a significant decrease in PBF values ($P < 0.05$), while lateral luxation and extrusion type-related PBF values showed no significant difference between the session-related values ($P > 0.05$). PBF measurements did not change over time for the contralateral incisors ($P > 0.05$). Teeth affected by an intrusion-type luxation injury remained unresponsive to sensitivity testing at follow up, while 3 (60%) developed grey discoloration of the crown. LDF may become useful in the detection of ischemic episodes of luxated maxillary central incisors after repositioning and splinting. Further studies are warranted to assess the validity of post-traumatic 'ischemic episodes' by comparing it to histological tooth pulp changes.

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Dental injuries to permanent incisors are a frequent finding following orofacial trauma. In epidemiological studies, the prevalence of traumatized permanent anterior teeth varied from 2.6 to 30% (1–10). Traumatically displaced or avulsed permanent teeth require a splint for stabilization following repositioning or replantation (11, 12). Treatment outcome of dislocated teeth may be influenced by several factors, such as degree of dislocation, concomitant dentoalveolar injuries, stage of root formation, time period between trauma and treatment, and type of dental trauma splint. The course of healing of the severed periodontal ligament and the neurovascular supply to the pulp determine the treatment outcome of the injured teeth.

Electrical and thermal pulp tests are unreliable following a traumatic dental injury with a possible absence of response to both tests even if the circulation is restored (13, 14). Therefore, the clinical evaluation of a traumatized tooth requires symptomatic, visual, and radiographic assessment. If the tooth becomes necrotic and infected, an external inflammatory root resorption may occur, which may result in tooth loss in a short time period (15). In teeth with incomplete root formation, circulation survival, and revascularization is possible (13, 16, 17); this may maintain

an infection-free pulp space, and allow the tooth to continue to develop and strengthen.

Pulpal blood-flow (PBF) measurement using laser Doppler flowmetry (LDF) has been described as a more sensitive technique for evaluating tooth vitality compared with conventional methods such as electrical and thermal pulp testing (18, 19). Several authors reported the use of flowmetric values to demonstrate the re-establishment of vitality in traumatized teeth (18–20) or to show significant blood flow reduction in maxillary teeth in patients undergoing Le Fort I osteotomy (21–24). In instance of dental trauma, LDF may be useful in the detection of transient ischemic episodes and the identification of teeth at risk for adverse sequelae such as avascular necrosis and tissue loss. Regarding the fact that longitudinal luxation type-related LDF/PBF data are not available from the literature, the purpose of this study was to assess whether LDF could be used to detect short- and long-term changes of PBF values of luxated permanent maxillary central incisors after repositioning and splinting.

Materials and methods

Subjects

The study group of 18 patients undergoing dental trauma splinting included 10 females and 8 males with a mean age of 22 years (range: 15–35 years). The subjects were informed about the study procedure and informed consent was received. Criteria for including a patient were (i) presence of a single permanent maxillary central incisor affected by an intrusion, lateral luxation, or extrusion type-related luxation type injury, (ii) absence of concomitant dento-alveolar injuries, and (iii) recentness of trauma <2 h. Each of the subjects was treated with a 0.16 in. $\times$ 0.50-in. wire (Standard Edgewise Wire, Leibinger, Mülheim, Germany). Where a maxillary incisor was missing, the injured maxillary central incisor bore a crown that was root-filled or had a large filling, LDF data were not collected.

Splint application

The splints were bonded to the labial aspect of all maxillary incisors. The wire was cut to the desired length and then adapted to the curvature of the maxillary incisors using pliers. The splints were secured with identical light-curing composite. After placing cotton rolls in the vestibule, the maxillary incisors were dried with air. Etching of the enamel surface was performed with 37% phosphoric acid gel for 30 s (Totaletch®, Ivoclar Vivadent, Ellwangen, Germany). Subsequently, the gel was rinsed off with water from the dental unit, and the etched surfaces were dried again. A thin layer of bonding agent (Heliobond®, Ivoclar Vivadent, Ellwangen, Germany) was applied using a microbrush. The bonding agent was left for 20 s prior to polymerization with a light source for another 40 s.

Apparatus

Pulpal blood flow measurements were performed with a laser Doppler flowmeter (Periflux PF 4001 Masters, Perimed, Järfälla, Sweden). Light with a wavelength of 632.8 nm was produced by a 1-mW He–Ne laser within the flowmeter and transmitted along a flexible fiber-optic conductor inside a specially designed round dental probe with a diameter of 2 mm (PF 416, Perimed) (21, 25–27). A fraction of the backscattered light from the tooth was returned to the flowmeter along a pair of afferent optical fibers within the probe. The optical-fiber diameter was 125 μm, and fiber-to-fiber distance was 500 μm. The flowmeter then processed the amount of Doppler-shifted light that was returned and produced an output signal. The measured voltage is linearly related to the flux of red blood cells (number of cells multiplied by their average velocity) encountered within the tooth and represents a relative measure of PBF.

The flowmeter was calibrated prior to each data collection session. The narrow band was adjusted to read zero voltage when the probe was placed against a motionless object, while a commercially available motility standard (Perimed) was used to calibrate the flowmeter on the wide band to a specific value of 250 perfusion units (PU). The artifact filter was activated, and the PBF data were collected on a wide band setting. Voltage output values were sent from the RS-232 port of the flowmeter at a rate of 32 signals per second to an Apple Macintosh Plus computer for storage and subsequent analysis.

Procedure

Measurements were recorded on the labial site of each experimental tooth at a location about 5 mm from the gingival margin. For each subject, four measurement sessions, on the day of splint removal, and 12, 24, and 36 weeks after splint removal were performed. In order to ensure accurate and reproducible spatial positioning of the probe at each session, custom-made clear plastic splints (Bioplast, Schen-Dental, Iserlohn, Germany) were prepared, covering the maxillary incisors, canines, and premolars and providing appropriately placed holes with a diameter similar to that of the flowmeter probe. After having the patient rest in a supine position in the dental chair for approximately 10 min, blood-flow data were collected for 3 min at each measurement session. The temperature of the room was constant. Attempts were made to

minimize bias as a result of movement of the subjects or probe. Pulse rate and blood pressure were also recorded.

On the day of splinting and splint removal and 12, 24, and 36 weeks after splint removal, the affected teeth were evaluated both clinically and radiographically. The clinical diagnostic procedures included sensitivity testing with carbon dioxide ice, percussion and mobility testing with a calibrated instrument (Periotest), and evaluation of crowns for the presence of changes in color (28). The radiographic examination of the anterior region consisted of one occlusal film and three periapical exposures, where the central beam was directed between the lateral and central incisors and between the central incisors (28).

In order to account for the temporal variability associated with repeated PBF measurements (25), a control group was included. At each session, when a luxated permanent maxillary central incisor was recorded, the respective contralateral homologous tooth was used as a control.

Data analysis

The mean perfusion unit for each recording site was calculated during each session by averaging all the individual perfusion units collected for 180 s. Individual perfusion units that registered as movement artifacts were excluded from this average. Univariate analysis of variance with Bonferroni correction for multiple tests was used to test for statistically significant differences between luxation type- and session-related variations in PBF measurements. Statistical significance was set at $P < 0.05$. For all statistical analyses, the SPSS × package (SPSS Inc., 1997) was used.

Results

On the day of splinting, a negative response to sensitivity testing and a positive response to percussion and mobility testing were the majority findings in the various luxation groups (from 87.5 to 100%). At session II, a positive response to percussion testing was relatively common in all diagnostic groups (from 37.5 to 60%); tooth mobility was minimally represented in the lateral luxation-type group (12.5%). From session III to IV, discoloration of the crown and periapical radiolucency were the most prevalent in the intrusion-type group (60.0 and 100%, respectively), and less common in the extrusion-type group (40 and 80%, respectively) and lateral luxation-type group (12.5 and 25%, respectively) (Table 1).

Analyzing the data according to luxation type-related measurements, there was a significant decrease in PBF values from session I to II ($P = 0.0039$), and from session III to IV ($P = 0.0005$) for teeth affected by an intrusion-type luxation, while

Table 1. Luxation type-related clinical findings ($n = 18$)

	Clinical and radiographic findings														
	Day of splinting			Session I			Session II			Session III			Session IV		
Criteria	Intr. Lux. (%) ($n = 5$)	Lat. Lux. (%) ($n = 5$)	Extr. Lux. (%) ($n = 8$)	Intr. Lux. (%) ($n = 5$)	Lat. Lux. (%) ($n = 5$)	Extr. Lux. (%) ($n = 8$)	Intr. Lux. (%) ($n = 5$)	Lat. Lux. (%) ($n = 5$)	Extr. Lux. (%) ($n = 8$)	Intr. Lux. (%) ($n = 5$)	Lat. Lux. (%) ($n = 5$)	Extr. Lux. (%) ($n = 8$)	Intr. Lux. (%) ($n = 5$)	Lat. Lux. (%) ($n = 5$)	Extr. Lux. (%) ($n = 8$)
Absence of sensitivity	5 (100)	5 (100)	7 (87.5)	5 (100)	3 (60.0)	6 (75.0)	5 (100)	3 (60.0)	6 (75.0)	5 (100)	5 (100)	7 (87.5)	5 (100)	5 (100)	7 (87.5)
Reaction to percussion	5 (100)	5 (100)	5 (100)	3 (60.0)	2 (40.0)	3 (37.5)	3 (60.0)	1 (20.0)	–	3 (60.0)	1 (20.0)	–	2 (40.0)	1 (20.0)	–
Mobility	–	5 (100)	8 (100)	–	1 (12.5)	–	–	1 (12.5)	–	–	1 (12.5)	–	–	1 (12.5)	–
Discoloration of crown	–	–	–	–	–	–	2 (40.0)	1 (12.5)	–	2 (40.0)	1 (12.5)	1 (12.5)	3 (60.0)	2 (40.0)	1 (12.5)
Periapical radiolucency	–	–	–	–	–	–	1 (12.5)	1 (12.5)	–	3 (60.0)	2 (40.0)	1 (12.5)	5 (100)	4 (80.0)	2 (25.0)

Intr. Lux., intrusive luxtion; Lat. Lux., lateral luxation; Extr. Lux., extrusive luxation; CO_2, carbon dioxide; and n, number of teeth.

Table 2. Means and standard deviations of luxation type- and control group-related PBF measurements ($n = 18$).

Sample	PBF value (PU)			
	Session I	Session II	Session III	Session IV
Diagnostic group ($n = 18$)				
Intrusive luxation type ($n = 5$)	5.3 ± 1.6	$3.6 \pm 0.8^{*}$	2.3 ± 0.3	$0.9 \pm 0.8^{**}$
Lateral luxation type ($n = 5$)	7.5 ± 4.0	7.8 ± 4.7	7.6 ± 4.8	6.8 ± 5.1
Extrusive luxation type ($n = 8$)	5.6 ± 3.2	6.0 ± 3.9	6.4 ± 4.3	6.8 ± 4.8
Control group ($n = 18$)	10.2 ± 4.0	10.2 ± 3.9	10.1 ± 3.4	10.4 ± 4.1

PBF, pulpal blood flow; PU, perfusion units; $^{*}P = 0.039$; $^{**}P = 0.005$, significant session-related difference; and *n*, number of teeth.

no significant difference between the post-splinting values was found for lateral luxation and extrusion type-related PBF values ($P > 0.05$). PBF did not change over time for the control group ($P > 0.05$) (Table 2).

Discussion

The purpose of this study was to assess whether LDF could be used to detect short- and long-term changes of PBF values of luxated maxillary central incisors after repositioning and splinting. The data indicate that the significant decreases in PBF values could be established at the 12-week follow up for intrusion-type luxations, which is a much earlier time period than that would be expected from the standard clinical tests. In several studies, pulp necrosis was described as the most common complication after luxation injuries (29), and occurred in almost all intrusions of fully formed permanent teeth (28, 32). Prophylactic extirpation of the pulp has been recommended to prevent other complications arising from the pulp necrosis (31, 32). Therefore, LDF may be used to monitor incisors during the post-trauma phase. It may help to identify 'ischemic episodes' long before this may be derived from traditionally clinical tests. In terms of 'clinical decision-making', a randomized clinical trial evaluating outcome measures of maxillary central incisors-related PBF values in specified 'non-trauma' and 'luxation subtype' treatment groups may be warranted to assess the diagnostic validity of the LDF-related variable 'PBF'. With regard to the suggestion that diagnosis of 'decreased PBF value' is predictive for luxation subtype-related 'adverse clinical sequelae conditions', follow-up studies would be in order to test whether changes in clinical outcome measures may be associated with appropriate changes in PBF values, using control data obtained from the respective 'non-adverse clinical sequelae' instances.

The present study showed that the LDF measurement was able to detect changes in PBF values after splint removal. Intrusion type-related PBF values were associated with a significant decrease in PBF values, while lateral luxation and extrusion type-related showed no significant difference between the session-related values. PBF values remained above 5 PU in lateral- and extrusive-related luxation types, whereas in intrusion-related luxation types the PBF value approached and dropped below 2 PU. This is of clinical significance and may be implicated as a possible cause in the development of subsequent degenerative and atrophic pulpal changes. With respect to measurement validity, further studies may be warranted to correlate the magnitude and duration of ischemic episodes with histological findings in the pulp.

Treatment outcome of luxated maxillary central incisors may not depend only on luxation type but also on other factors such as degree of dislocation, concomitant dento-alveolar injuries, stage of root formation, time period between trauma and treatment, and type of dental trauma splint. However, the contribution of these variables is unknown. Further investigations are necessary to answer the question which additional trauma-related features may have to be defined as 'diagnostic for disorder', namely with significant elevated risk for adverse sequelae.

Pulpal blood flow values for maxillary incisors in adults are described to range from 7.6 to 14 PU for central incisors (21, 26). From a clinical perspective it is important that in the present study PBF values remained above 5 PU after splint removal, except for intrusive-related luxation types. Traumatic intrusion is a type of dental injury that involves displacement of the tooth into the alveolar socket. This type of injury usually involves the maxillary anterior teeth and is more common in the primary dentition than the permanent dentition (2). Intrusion represents a very complex wound, involving disruption of the marginal gingival seal, alveolar bone, periodontal ligament fibers, cementum, and the neurovascular supply to the pulp (28). Complications include ankylosis (28, 29, 33), pulp necrosis, pulp obliteration, external root absorption, and loss of marginal bone support (34). The most significant prognostic factor for pulpal healing appears to be the stage of root formation at the time of injury (29). In teeth with incomplete root formation, slight movement of the apex may presumably occur without disruption of the blood vessels passing through the apical foramen (28).

The main objective of this study was to analyze changes in PBF values after splint removal. The method for measuring PBF values may be used as a diagnostic tool in dental traumatology. The LDF measurement may be of particular interest for follow-up investigations to identify changes in PBF. It may be a useful tool in monitoring PBF in splinted teeth to detect early decreases in PBF in repositioned luxated teeth. The dog model has previously been used to demonstrate revascularization (35–37) and the ability of LDF to differentiate vital from non-vital pulp has been demonstrated (19, 38, 39). LDF readings were found to be highly accurate in differentiating a revascularized tooth from a necrotic pulp tooth, while the accurate LDF reading of pulpal revascularization could be established about 30 days after re-implantation. In addition, a continued increase in blood supply with pulpal blood anastomoses after 30 days was found, an observation that corresponds to the report that PBF values continued to increase from 4 to 12 weeks after re-implantation. Clinically, therefore, it appears that the LDF assessment for human teeth should be done for the first time about 30 days after trauma continued intermittently for 3–6 months.

The results of the present study may suggest the luxation type of intrusion to be associated with a significant short- and long-term reduction in central incisor-related PBF values. However, as no separate group of subjects has been used as controls, and the investigated intrusion group may be regarded as the sum of different intrusion subtypes, studies involving a larger number of subjects, using appropriate controls and more specified inclusion criteria may be warranted to demonstrate any luxation type-specific effect. In addition, LDF assessment of PBF is highly susceptible to environmental and technique-related factors. The fact that variables such as probe holder design (27, 40), gingival isolation device (27), flowmeter characteristics (27), and mineralization of enamel and dentine (41) may be significantly related to the different LDF techniques of positioning the optical probes at cervical, central, or occlusal tooth sites (25, 27) indicates the need for further studies to provide technique-related data for intra- and inter-observer reliability to gain consistent testing and diagnosis in the evaluation of PBF.

Laser Doppler flowmetry may be used to assess the degree and duration of dental trauma-related ischemic episodes, thereby identifying patients at risk for adverse sequelae such as avascular necrosis and tissue loss. Although intrusive luxation is uncommon as compared to other types of traumatic injury in the permanent dentition, constant attention must be given to the pulp tissue and periodontal structures, because of the high frequency of complications following this type of injury. In addition, the complication may be unpredictable and the treatment becomes complex and has to be adaptable to any complications that may arise. The outcomes of repositioning may vary and may not be predicted from the appearance or extent of injury sustained clinically. Further studies are warranted to assess the validity of post-traumatic LDF/PBF measurements by comparing it to histological tooth pulp changes, and by determining how well diagnoses of PBF may predict course and response to treatments in clinical trials.

Conclusions

Laser Doppler flowmetry (LDF) may become useful in the detection of ischemic episodes of luxated permanent maxillary central incisors after repositioning and splinting. Further studies are warranted to assess the validity of post-traumatic 'ischemic episodes' by comparing it to histological tooth pulp changes.

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